The *ut* and *re* of the next octave higher would have given us 16 beats, that of the next 32, that of the next 64, of the fourth octave 128, and that of the fifth 256. But 256 per second is a rapidity far too great for the ear to hear as separate sounds. If there were 256 separate impulses, they would blend to give us the note $ut_3 = 256$. They are not *impulses*, but *beats*: nevertheless, they blend. Dr. Kœnig strikes the ut_6, then the re_6, both shrill sounds when you hear them separately; but when he strikes them in quick succession one after the other, at the moment when the mallet strikes the second fork you hear this clear ut_3 sounding out. I am not going to waste your time in a disputation as to whether the sound you hear is objective or subjective. It is enough that you hear it, pure and unmistakable in pitch. It is the grave harmonic; and the number 256, which is its frequency, corresponds to the positive remainder when you divide 2304 by 2048.

Now let me give you a beat-tone belonging to the superior set: it also will be a grave harmonic, if you so please to call it; but its frequency will correspond neither to the difference nor to the sum of the frequencies of the two primary tones. Dr. Kœnig takes $ut_6 = 2048$ as previously, and with it $si_6 = 3840$. Let us calculate what the superior beats ought to be. 2048 goes into 3840 twice, less 256. Then, 256 being the negative remainder, we ought to hear from these two forks the beat-tone of 256 vibrations, which is ut_3, the same note as in our last experiment. He strikes the forks, and you hear the result. The beat-tone, which is neither a differential tone nor a summational tone, corresponds to the calculated number of beats.

If I take $ut_6 = 2048$ and $sol_6 = 3072$, the two remainders both come out at 1024, which is ut_5. Dr. Kœnig will first sound ut_5 itself, separately, on an ut_5 fork, that you may know what sound to listen for. Its sound has died away; and now he strikes ut_6 and sol_6, when at once you hear ut_5 ringing out. That sound which you all heard corresponds to the calculated number of beats. That is enough for my present purpose.

The next illustration is a little more complex. I select a case in which the beat-tones corresponding to the inferior and the superior beats will both be present. We shall have four tones altogether—two primary tones and two beat-tones. The forks I select are $ut_6 = 2048$, as before, and a fork which is tuned to vibrate exactly 11 times as rapidly as ut_3—it is the 11th harmonic of that note, but does not correspond precisely to any note of the diatonic scale. It has 2816 vibrations, and is related to ut_6 as 11 : 8. The two remainders will now be 768 and 1280, which are the respective frequencies of sol_4 and mi_5. Dr. Kœnig will first sound those notes on two other forks, that you may know beforehand what to listen for. Now, on striking the two shrill forks in rapid succession, the *two* beat-tones are heard.

If I select, instead of the 11th harmonic, the 13th harmonic of ut_3, vibrating 3328 times in the second, to be sounded along with ut_6, the same two beat-tones will be produced as in the preceding case; but $mi_5 = 1280$ is now the inferior one, corresponding to the positive remainder, whilst $sol_4 = 768$ is the superior tone, corresponding to the negative remainder. It is certainly a striking corroboration of Dr. Kœnig's view that the beat-tones actually heard in these last two experiments should come out precisely alike, though on the old view, that the combinational tones were simply the summational and differential tones, one would have been led to expect the sounds in the two experiments to be quite different.

One other example I will give you of a beat-tone belonging to the second period. The two primary notes are given by the forks $ut_5 = 1024$ and $re_6 = 2304$. The beat-tone which you hear is $ut_3 = 256$, which corresponds to the positive remainder.

It will be convenient to draw up in tabular form the results just obtained. These may be considered as abbreviations of the much more extended tables drawn up by Dr. Kœnig, which hang upon the walls, and which are to be found in his book, "Quelques Expériences d'Acoustique."

TABLE II.

Sounds of Primary Beats.

Primary Tones.			Ratio.	Inferior Beat-tone.	Superior Beat-tone.
ut_6 2048	re_6 2304	...	8 : 9	$1\left\{\begin{matrix} ut_3 \\ 256 \end{matrix}\right.$	—
ut_6 2048	si_6 3840	...	8 : 15	—	$1\left\{\begin{matrix} ut_3 \\ 256 \end{matrix}\right.$
ut_6 2048	sol_6 3072	...	8 : 12	$4\left\{\begin{matrix} ut_5 \\ 1024 \end{matrix}\right.$	$4\left\{\begin{matrix} ut_5 \\ 1024 \end{matrix}\right.$
ut_6 2048	(11th) 2816	...	8 : 11	$3\left\{\begin{matrix} sol_4 \\ 768 \end{matrix}\right.$	$5\left\{\begin{matrix} mi_5 \\ 1280 \end{matrix}\right.$
ut_6 2048	(13th) 3328	...	8 : 13	$5\left\{\begin{matrix} mi_5 \\ 1280 \end{matrix}\right.$	$3\left\{\begin{matrix} sol_4 \\ 768 \end{matrix}\right.$
ut_5 1024	re_6 2304	...	4 : 9	$1\left\{\begin{matrix} ut_3 \\ 256 \end{matrix}\right.$	—

(*To be continued.*)

THE ORIGIN OF THE GREAT LAKES OF NORTH AMERICA.

At one time glaciers—perhaps in the co-operative society of an ice-sheet—were gravely suspected of having excavated even the great lakes of North America. This, however, is hardly probable. The *a priori* difficulties in the hypothesis are great. Apart from objections which have often been pointed out, the work done would be on so gigantic a scale that a longer period must be assigned to the glacial occupation of the region than seems probable from other considerations. Further, the direct evidence which will presently be noticed seems conclusive against the hypothesis; but it may be affirmed with better reason that ice has indirectly aided in the process, though to what extent we can, as yet, hardly venture to say.

During the last few years numerous observations have been made, both in Canada and in the United States, upon the configuration of the lake beds, and the elevation of their ancient margins. To some of these Dr. Wright refers in his volume on "The Ice Age in North America," and Prof. J. W. Spencer (who has been engaged on this subject for several years) brings them into a focus in a paper recently published in the Quarterly Journal of the Geological Society of London.[1]

At first sight the great lakes, from Superior to Ontario, are suggestive of glacial excavation. They seem to occupy true rock basins. Superior discharges into Huron over the ledges—once a "portage"—of Sault Ste. Marie. Huron, as it were, leaks into Erie, the fall between the two sheets of water being only nine feet. Erie flows towards Ontario over the rocky rapids and the final precipice of Niagara; and the St. Lawrence, after leaving Ontario, gives frequent evidence of a rocky bed, the level of which is considerably above that of the bottom of the lake, for the depth of this near its eastern end is more than seven hundred feet. But more careful investigation of the lakes has shown that in these apparently perfect basins (as is sometimes discovered in household affairs) hidden cracks exist, which, under different physical conditions, would have let the water run out. This indeed is not the whole story; another agency must be presently mentioned; but that these apparent basins once had

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[1] Vol. xlvi. p. 523 (read April 16, 1890).

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outlets, by which they would have been drained, at any rate partially, seems beyond question.

The following is a brief statement of the results of sounding in the water and boring on the land. The surface of Lake Superior is 630 feet above sea-level, the deepest part of its bed 375 feet below that datum plane. The fall from the shore line is generally rather rapid; a large part of the basin is more than 300 feet deep, and a considerable area is below 600 feet. The original outlet, according to Dr. Wright, was on the southern side; and by this, in pre-glacial times, the drainage was discharged towards the Mississippi. But, apparently, the information in regard to the ancient valley-system of the Lake Superior area is less complete than in the case of the other lakes.

The Huron-Michigan basin at once arrests attention by its extraordinary outline. Michigan is a gigantic backwater without inclosing hills at its southern or upper end. Huron proper is almost divided from Georgian Bay by the Indian Peninsula and a chain of rocky islands, of which Manitoulin Island is the chief. All this is far more suggestive of submergence than of any other mode of formation. Closer study has confirmed first impressions. Michigan really consists of two basins, divided by a plateau submerged at a maximum depth of 342 feet; the northern and larger basin sinks to a depth of 864 feet, the southern one only descends to 576 feet. Hence, if the level of the water were lowered by 350 feet, Michigan would be divided into two lakes.

Of these, the former must have drained into the north-west end of Lake Huron. It is true that the deepest soundings at the present outlet do not exceed 252 feet, but near this a fjord-like channel has been traced in the shallower part, trending northward, with a depth of 612 feet, and there are indications of other buried channels. Thus there can be little doubt that in pre-glacial times the northern basin of Michigan communicated, as the lake still does, with that of Lake Huron. But as to the outlet of the southern basin there is some dispute. Prof. Spencer, however, states that a buried channel has now been traced along the valley of the Grand River, across the peninsula of Michigan to Saginaw Bay on Lake Huron. Its exact depth has not been ascertained, but it has been pierced in several places to depths of from 100 to 200 feet below the level of the lake, and in one case the drift was found to extend 500 feet below the surface of the ground, and 350 below that of Lake Huron.

Next as to the drainage of this lake. Submerged channels resembling river valleys have been traced along its bed. One is a prolongation, in a north-easterly direction, of that which has just been mentioned. Another runs to join it from the south—that is, in the opposite direction to that of the present flow of the water; and a third is a continuation of the channel which drained the northern basin of Michigan. These three ultimately come together, and the united valley rounds Cabot's Head, and makes for the southern end of Georgian Bay, keeping near its south-western side. Here also an ancient outlet has been found. Across the low flat land separating the waters of Georgian Bay from Lake Simcoe a buried channel has been struck in borings, at various depths—in one case 280 feet—below the surface of the latter. Between this and Lake Ontario, well-borings indicate that the drift is very deep, and that it conceals an ancient channel, which entered Lake Ontario some thirty miles west of Toronto. Lake Erie, which is generally less than 84 feet deep, also exhibits a buried system of ramifying valleys, and the line of discharge into Ontario was not over the lip of Niagara but by a deep valley, now choked with drift, which can be traced several miles to the west of the present course of the St. Lawrence. In Ontario, also, a channel has been found, the greatest depth of which is over 700 feet below the surface of the lake. This runs near the southern shore, and receives other valleys from this direction.

The conclusion to which these investigations point is that in pre-glacial times the great lakes did not yet exist, but their site formed part of a system of river valleys, which ultimately coalesced in one main channel, now concealed beneath the waters of the eastern part of Ontario. Of these valleys, the one was cut off from the united system of the other tributaries at Detroit, and the head waters of these were parted by the plateau now buried beneath Lake Michigan. Some, indeed, have contended that the water of these rivers passed from the Ontario region towards the Hudson, but Prof. Spencer considers that they were even then tributary to the St. Lawrence.

But it would not suffice to block these channels with glacial drift. Parts of Lake Superior, the southern basin of Michigan, a little of Huron, and the eastern end of Ontario are beneath the sea-level: the last as much as 491 feet below it. We must assume in addition a considerable downward movement of the whole area, otherwise these valleys could never have emptied themselves into the sea. To drain the valley occupied by Ontario would require, at the least, an elevation of more than 700 feet; Southern Michigan, of not much less, perhaps of more. This hypothesis, however, presents no real difficulty, for it can be proved that many regions have been affected by movements, both upwards and downwards, in glacial or post-glacial times. The coast of Norway and many parts of northern America have been affected by a great downward movement—amounting not seldom to at least a thousand feet, and sometimes even as much as a thousand yards. This, again, after the ice had melted away and the main physical features of the district were sculptured, was followed by one in the contrary direction, which may be occasionally measured by some hundreds of feet; as, for example, at the beaches of Novaya Zembla, the terraces of the Varanger Fjord, and of many another inlet in Norway. Of this movement also there is proof on the Fraser and other rivers in America.

But to convert Lake Ontario into a river valley it would not be enough to give a general uplift and clear away the dams of glacial drift. Differential movements of the earth's crust are required. That these have sometimes occurred has been long since proved, in the case of Norway. Now, careful observations, by Prof. Spencer and others, show the reasonableness of the hypothesis in the district of the great lakes. Around their shores are old terraces, which extend in some cases to a height of 1700 feet above the present water-level, and are indicative, in Prof. Spencer's opinion, of a depression to that amount. A series of careful measurements undertaken on different terraces and around more than one American lake prove that these terraces do not correspond with the existing contour lines, but have been affected by a differential uplift, amounting in one case to as much as 4 feet per mile.

Hence, it follows that the great North American lakes are of comparatively modern date, and are nothing more than a great system of river valleys, which have been converted into a chain of huge lakes, partly by the blockage of old channels, partly by differential movements of the earth's crust. If this view be established, and the evidence in its favour (which finds much support from other regions) appears very strong, it will help in elucidating several important questions, bearing on not only the history of the Glacial epoch and the exact mode of the accumulation of the *débris*, but also on the cause of the movements of a crust which is asserted by physicists to be rigid. But into these questions, fascinating as they are, want of space precludes us from inquiring on the present occasion.

T. G. BONNEY.

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